Effects of microbial agents to the properties of fly ash-based paste

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Abstract. Specific microbial agents such as bacteria are often used in concrete to improve its performance. Some microbes act as self-healing agents to close cracks in concrete, and to increase concrete strength. This paper presents a study to observe the effects of microbe addition to two types of concrete mixtures the fly ash-based, as geopolymer paste, and portland cement paste containing fly ash. Furthermore, the investigation was conducted to compare the properties of each paste, such as its compressive strengths, specific gravities, porosity, microstructures, and X-Ray diffracting properties. The results indicate that microbial activities positively affected the properties of both, portland cement paste and geopolymer paste. The result reported here strongly suggests that fly ash can be used to produce a high quality, but environmental friendly construction material when it's mixed together with useful microbes.

1 Introduction

The approach of biochem technology is often used to increase the properties of cement-based materials called bio-mineralization [1]. Microorganisms, including bacteria, fungi, and algae, responsible for the production of biominerals such as carbonate, silicate, and calcium phosphate [2-4] are useful as concrete filler. Bacteria from the genus *Bacillus* and *Sporosarcina* are one of the most widely used that has the ability to tolerate high pH, temperature, alkaline conditions, and live inside the concrete [5,6]. It is caused by a precipitate ion of CaCO_3 , from converting urea into ammonium and carbonate [7] and change the properties of the concrete mixtures and soil structures [8,9]. This type of bacteria forms endospores [10,11], so that it can survive without nutrients and water for hundreds of years [12]. The utilization of bacteria as the healing agent in concrete mixture to form self-healing concrete has been widely investigated [1,5,6,12-15]. It is found that the calcium carbonate as microbes product, not only for healing the micro cracks, but also responsible to change the properties of the concrete mixtures [6]. Another research

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elucidates that simply adding bacteria to the concrete mixture is ineffective, as water is one of the major components of the mixture [16]. It makes the microbes scattered to all the matrix of concrete. Therefore, isolation is an alternative way to resolve this problem. Isolation materials should be strong enough to survive the mixing process, but brittle when the crack occurs, and it must have a strong bond with the concrete matrix [12]. Geopolymer paste and cement paste are some examples of potential isolator. The usage of fly ash in geopolymer paste influenced its compressive strength. However the compressive strength is more affected by fineness specific area and soluble content of fly ash. But the physical and chemical characteristic of fly ash affected the geopolymer paste more significantly than cement paste [17]. This paper proposes the effect of additional microbes in the fly ash-based paste. The paste made from portland cement based associated with high volume of fly ash and fly ash-based geopolymer paste. The effectiveness of microbes activities in the paste is one of the important factors to apply the paste as potential material or artificial aggregates.

2 Materials

2.1 Fly ash

A class F of fly ash was collected from Suralaya Coal Fire Power Plant, Banten, Indonesia, as the raw material. The chemical compositions oxides of fly ash are provided in Table 1.

Table 1. Chemical compositions of fly ash by X-Ray Fluroscent (XRF) analysis.

Oxides	SiO ₂	Al ₂ O ₃	CaO	Fe ₂ O ₃	K ₂ O	MgO	Na ₂ O	SO ₃	TiO ₂
(% by weight)	44.83	29.23	4.47	4.66	0.68	1.62	1.32	0.62	0.84

2.2 Alkali activator

The two types of alkali activators that were used are natrium silicate (Na₂SiO₄) and natrium hydroxide (NaOH). Four molars of natrium hydroxide solution was used in this study. The mass ratio of natrium silicate to natrium hydroxide was kept constant at two.

2.3 Portland cement

Portland cement that was used in this paper is Ordinary Portland Cement (OPC) with 3.14 gram/cm³ in density. OPC was collected from Varia Usaha Beton, Gresik, Indonesia. The chemical compositions of OPC are listed in Table 2.

Table 2. Chemical compositions of OPC by X-Ray Fluroscent (XRF) analysis. [18]

Oxides	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	SO ₃
(% by weight)	20.92	5.49	3.78	65.21	0.97	2.2

2.3 Microbial agent

Sporosarcina pasteurii and yeast from fungi were used in this study as the microbial agent in a solution form. The microbial agent solutions are the commercial products from Biocon, Sidoarjo, Indonesia.

3 Mix proportions and test methods

The two types of fly ash-based concrete mixture in this paper are geopolymer paste and portland cement paste. Mixing proportions is provided in Table 3. Microbes was added at the end of the mixing process until it is homogeneous.

Table 3. Mixing proportions (% by weight).

Mixtures	Alkali Activator	Fly Ash	OPC	W/C Ratio	Microbial Agents
P	35 %	65 %	-	-	-
PB	35 %	65 %	-	-	400 ml/m ³
C	-	65 %	35 %	0.3	-
CB	-	65 %	35 %	0.3	400 ml/m ³

Table 3 shows the code that was used, code P for geopolymer paste and C for cement paste, both without microbial agents. Then, PB and CB, are the opposite of them, literally with additional microbes in its mixtures. The specimens were conducted for cylindrical shape with a diameter of 5cm and height of 10cm as Fig 1.

Fig. 1. Cylindrical shape of specimens.

Test methods were conducted to obtain the properties of the fly ash-based paste in this paper. Moist curing was conducted to all samples in this study. Compressive strength and specific gravity tests were conducted to obtain the mechanical properties of the specimens according to ASTM C39 [19] and ASTM C128 [20], respectively. A compression test is the important test related to indicate the mechanical properties of concrete. Porosity tests were set up to find the porosity as the physical properties that related to compressive strength of the concrete. X-Ray Diffractometer (XRD) tests were conducted to analyze the chemical compositions [21]. Scanning Electron Microscopy (SEM) were set up to obtain the microscopy scale of the specimens in each mixture.

4 Results and discussions

4.1 XRD analysis

XRD analysis was conducted at a 28-day age of the specimens. The amount of oxides from the analysis are listed in Table 4.

Table 4. Mineral compositions of mixtures by XRD analysis.

Geopoymer Paste			Portland Cement Paste		
Oxides	P	PB	Oxides	C	CB
Mullite (Al ₂ SiO ₄)	41.6 %	32.8 %	Mullite (Al ₂ SiO ₄)	38.9 %	27.5 %
Zeolite (Al ₃ NaH ₁₂ KO ₂₂ Si ₅)	31.7 %	38.7 %	Tobermorite (Ca ₃ HO ₉ Si ₃)	32.3 %	36.4 %
Calcite (CaCO ₃)	7.9 %	14.7 %	Calcite (CaCO ₃)	14.0 %	26.0 %
Quartz (SiO ₂)	14.8 %	13.8 %	Quartz (SiO ₂)	9.9 %	9.0 %
Rutile (TiO ₂)	4.0 %	0.1 %	Rutile (TiO ₂)	4.9 %	1.1 %

According to Table 4, mullite is the highest oxide in each paste, except CB paste, and rutile is the lowest. Rutile was obtained from fly ash that was used in this study. The peak of quartz intensity of P is the highest while the lowest belongs to C. Calcite increased when there is an additional microbial agents inside the paste, as the result of the bacterial metabolism. It shows that bacteria influenced the content of calcite, according to the XRD result. Geopolymer paste has a higher amount of quartz than cement paste in all mixtures.

4.2 Compressive strength

The strength developments were observed at 7, 14, and 28 days age of the paste. These test result is shown in Fig 2.

Fig. 2. Strength development of mixtures.

Generally, Fig.2 describes that all compressive strengths increase as the paste aging. According to the data, CB has the highest compressive strength in every observation time. The strength of PB is higher than P, and CB is higher than C. The strength developments of the paste were influenced by bacteria metabolism inside, along 28-days observations. It has relation with the amount of calcite that were produced by bacteria as the result of XRD analysis. It shows that microbial activity positively affected fly ash-based paste.

4.3 Specific gravities

Specific gravities of the paste were obtained at 28 days age of the paste. These test result for P, PB, C, and CB, are 1.83 gr/cm³, 1.84 gr/cm³, and 1.94 gr/cm³, 1.94 gr/cm³,

respectively. The adding of microbial agent in the paste mixtures has less influence to the specific gravity.

4.4 Porosity

Porosity test of the paste were obtained at 28 days age of the paste. These test result is shown in Fig 3.

Fig. 3. Strength development of mixtures.

According to the result in Fig. 3, the amount of opened porosity higher than closed porosity at all mixtures. Opened porosity is permeable pore that can be penetrated by air or water, while closed porosity is the opposite. Closed porosity is better because it represent the behaviour of concrete microstructure. PB have closed porosity higher than P. At the same time, CB have the highest amount of closed porosity, not only than C, but also than others. The result show that the adding of microbial agent in the paste mixtures affect the closed porosity.

4.5 The relationships between compressive strengths, calcite amounts, and closed porosity

The analysis elucidate that there is a relationship between compressive strengths, calcite amounts, and closed porosity. The relationship is shown in Fig 4.

Fig. 4. Relationships between compressive strengths, calcite amounts, and closed porosity

Fig 4. shows that the increasing of compressive strengths were influenced by the amount of closed porosity and calcites in the fly ash-based paste. In the paste with microbial agents, the amount of calcites higher than in the opposite paste, so does the amount of closed

porosity. It shows that the rising of calcite were caused by the microbial activity. The calcite fill the pores in the paste and influenced the compressive strength.

4.5 SEM-EDX analysis

SEM tests were obtained at 28-day age of the mixtures. The results of this test were described in Fig.5 with 5000 times magnification.

Fig. 5. SEM analysis of mixtures.

The PB and CB figure in Fig. 5 above show that there are hyphae as the result of yeast from fungi, but bacteria are not obviously by this observation. Hyphae looked like fibers in that figure. Hyphae can be the nest and food resources or bacteria. According to the observations, hyphae in geopolymer paste are more visible than in portland cement paste, in samples of age 28 days. Dimensions of hyphae in CB are slighter than in PB in this age.

5 Conclusions

1. The utilization of microbial agents to the fly ash-based paste improved the properties even though the amount of addition is small.
2. The compressive strength were influenced by the amount of calcite and porosity of fly ash-based paste.
3. Microbial agents affected the properties of fly ash-based paste, according to the sprout of hyphae that was proved by SEM test, the content of calcite by XRD, and its compressive strength and porosity.
4. Fly ash can be used to produce a high quality, but environmental friendly construction material when it's mixed together with useful microbial agents.

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